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Final Report
on
A URINE VOLUME MEASUREMENT SYSTEM

For
National Aeronautical and Space Administration
Manned Spacecraft Center
R & D Contract Branch
Contract NAS 9-11612

(Contract Period, April 29, 1971 to December 31, 1972)

December 1972

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I. INTRODUCTION

The NASA's medical and behavioral experiments program objectives of future manned space flights require that the urine volume of each individual void be determined. Presently, there are no satisfactory methods for making such determination. Therefore, NASA is seeking an improved urine volume measurement system for use in the unusual environment of manned space flight.

NASA's current urine transfer and collection system utilizes a blower that draws cabin air and urine through a duct into the urine collector in the zero-gravity environment. The volume measurement is made at a subsequent time. The major difficulty in making the measurement relates to the presence of air in the urine.

The system being studied by Geoscience utilizes a low time-constant thermal flowmeter. The time integral of the transient response of the flowmeter gives the urine volume during a void as it occurs. In addition, the two phase flows through the flowmeter present no problem. Developments of the thermal flowmeter and a verification of the predicted performance characteristics during the contract period are summarized in this report.

II. DESCRIPTION OF SYSTEM

The Geoscience "axial fluid temperature differential" flowmeter is briefly described as follows. Heat from an electrical heater is added to a thin wall tube through which a two-component mixture of urine and air is flowing. A thermopile that measures the axial temperature rise in the established flow region is positioned on the tube wall (the temperature field for this system is shown in Figure 1). The flow tube, heater, and thermopile are insulated from the surroundings by a foam layer or a vacuum jacket. The heat balance on the flowmeter at steady state is^{*}

$$q_H = (m_1 c_{p1} + m_2 c_{p2}) \Delta t_m \quad (1)$$

where

q_H , electrical heat input between the thermopile junctions

m_1 , urine mass flow rate

c_{p1} , urine heat capacity

m_2 , air mass flow rate

c_{p2} , air heat capacity

Δt_m , axial fluid temperature differential

The mass fraction of urine in the two-component mixture can be defined as

$$X_1 = \frac{m_1}{m_1 + m_2} \quad (2)$$

* The storage term is small under transient performance conditions if the thermal capacity of the system is low.

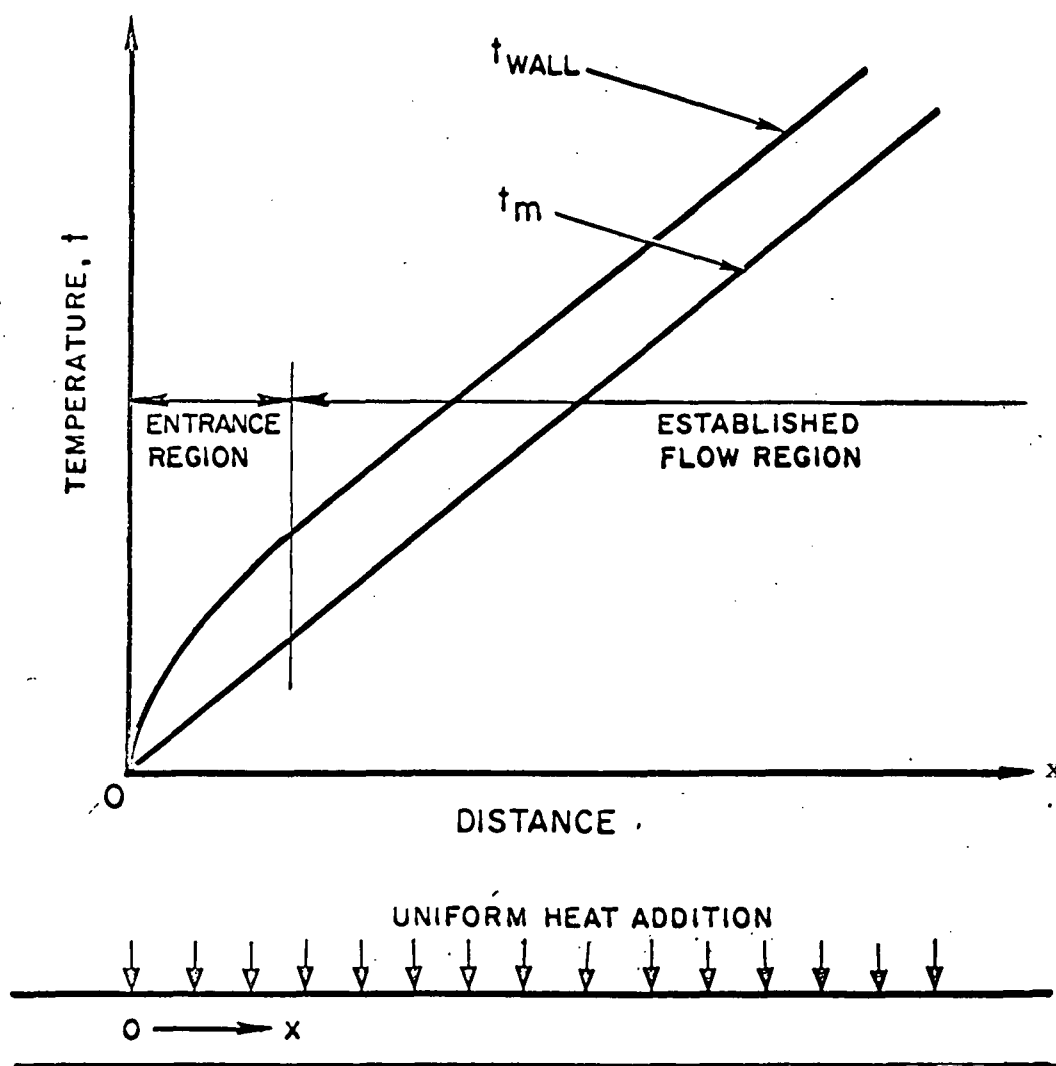


Figure 1. Entrance and Established Flow Region Descriptions

From Equations (1) and (2), the urine mass flow rate can be expressed as,

$$m_1 = \frac{q_H}{\left[c_{p1} + \left(\frac{1 - x_1}{x_1} \right) c_{p2} \right] \Delta t_m} \quad (3)$$

The thermopile voltage is given by,

$$E_s = n e \Delta t_m \quad (4)$$

where

n , number of thermocouple junction sets

e , thermoelectric power of the two dissimilar metals that comprise the thermopile

Substitution of Equation (4) into (3) yields,

$$\begin{aligned} m_1 &= \frac{q_H n e}{\left[1 + \left(\frac{1 - x_1}{x_1} \right) \left(\frac{c_{p2}}{c_{p1}} \right) \right] c_{p1} E_s} \\ &= \frac{K}{E_s} \end{aligned} \quad (5)$$

where

$$K = \frac{q_H n e}{\left[1 + \left(\frac{1 - x_1}{x_1} \right) \left(\frac{c_{p2}}{c_{p1}} \right) \right] c_{p1}} \quad (6)$$

It is of importance to examine the flowmeter constant K for the present application of two component urine-air flow. The mass flow rates in Equation (2) can be expressed as volumetric flow rates,

$$x_1 = \frac{m_1}{m_1 + m_2} = \frac{Q_1 \gamma_1}{Q_1 \gamma_1 + Q_2 \gamma_2} \quad (7)$$

where

Q , volumetric flow rate

γ , density

For the present application, the volumetric flow rates for the two components are of the same order of magnitude (say $Q_1 = Q_2$). For this case, x_1 becomes

$$x_1 = \frac{1}{1 + \frac{\gamma_2}{\gamma_1}}$$

or

$$\frac{1 - x_1}{x_1} = \frac{\gamma_2}{\gamma_1}$$

For urine, $\gamma_1 \cong 62.4 \text{ lbs/ft}^3$ and $c_{p1} \cong 1.0 \text{ Btu/lb } ^\circ\text{F}$ and for air $\gamma_2 = 0.075 \text{ lbs/ft}^3$ and $c_{p2} = 0.24 \text{ Btu/lb } ^\circ\text{F}$, the bracket term in Equation (6) becomes

$$\left[1 + \left(\frac{1 - x_1}{x_1} \right) \left(\frac{c_{p2}}{c_{p1}} \right) \right] = 1 + \left(\frac{0.075}{62.4} \right) \left(\frac{0.24}{1.0} \right)$$

$$= 1.00029$$

This result means that the presence of the gas component is unimportant in the heat balance of the flowmeter system for the urine mass fraction indicated. Note that even if the urine flow is reduced by a factor of

100, the effect of the gas component is still small.

The urine mass flow rate can be inversely related to the thermo-electric output signal, E_s (Equation (5)), and the urine volume is obtained by integrating the mass flow rate over time,

$$V_1 = \frac{1}{\gamma_1} \int_0^{\theta} m_1(\theta) d\theta \quad (8)$$

where

V_1 , urine volume

θ , time

III. INVESTIGATION OF POTENTIAL PROBLEM AREAS

1. Significance of Variations of Specific Heat and Density of Urine

The question of the influence of variations in urine density and heat capacity on the urine flow rate and volume determinations was identified at the beginning of the program. The following analytical treatment demonstrates that these property variations over wide ranges of void volume per day are not serious.

Urine consists mainly of water and small amounts of organic and inorganic constituents; namely, sodium and potassium chlorides and urea. From the known constituents, the density can be calculated for the mixture using the formula,*

$$\gamma = \frac{1}{\sum_{n=1}^n \frac{\omega_n}{\gamma_n}} \quad (9)$$

where

γ , density of mixture

ω_n , weight fraction of the n^{th} constituent

γ_n , density of the n^{th} constituent

This formula was used to predict the density of idealized urine mixtures made from 8.90 gm NaCl, 3.45 gm KCl, and 15 and 30 gm urea mixed in volumes of 600, and 2400 ml of water (the normal void range for an adult

* See Reference 5 in the Bibliography

in twenty-four hours). The results of these calculations are shown in Table I and are found to be in good agreement with the experimental range reported in the literature, namely, $1.003 < \gamma < 1.03$ gm/cc.

The heat capacity of idealized urine mixtures can be calculated from the following formula,*

$$c_p = \sum_1^n \omega_n c_{p_n} \quad (10)$$

where

c_p , heat capacity of mixture

c_{p_n} , heat capacity of the n^{th} constituent

ω_n , weight fraction of the n^{th} constituent

The heat capacity calculations for the mixtures used in the previous two examples are presented in Table II.

The property prediction methods used above have been found to be in good agreement with experimental values, as the references cited indicate. The density and heat capacity variations over the wide range of conditions shown are only a few percent. Further, in the flowmeter equations themselves, these two properties enter as a product; the mean variation of this product varies less than one percent. The effect of this result is verified by examining a typical flowmeter calibration curve (Figure 2), for both urine and water. These data indicate that no significant differences occur for these two liquids.

* See Reference 4 in the Bibliography

TABLE I. DENSITY PREDICTIONS

Water Volume ml	NaCl, gm	K Cl, gm	Urea, gm	Calculated density gm/cc
2400	8.9	3.45	30	1.0063
600	8.9	3.45	30	1.0250
2400	8.9	3.45	15	1.0047
600	8.9	3.45	15	1.0185

TABLE II. HEAT CAPACITY PREDICTIONS

Water Volume ml	NaCl, gm	K Cl, gm	Urea, gm	Calculated Heat Capacity, cal/gm °C
2400	8.9	3.45	30	0.988
600	8.9	3.45	30	0.950
2400	8.9	3.45	15	0.989
600	8.9	3.45	15	0.966

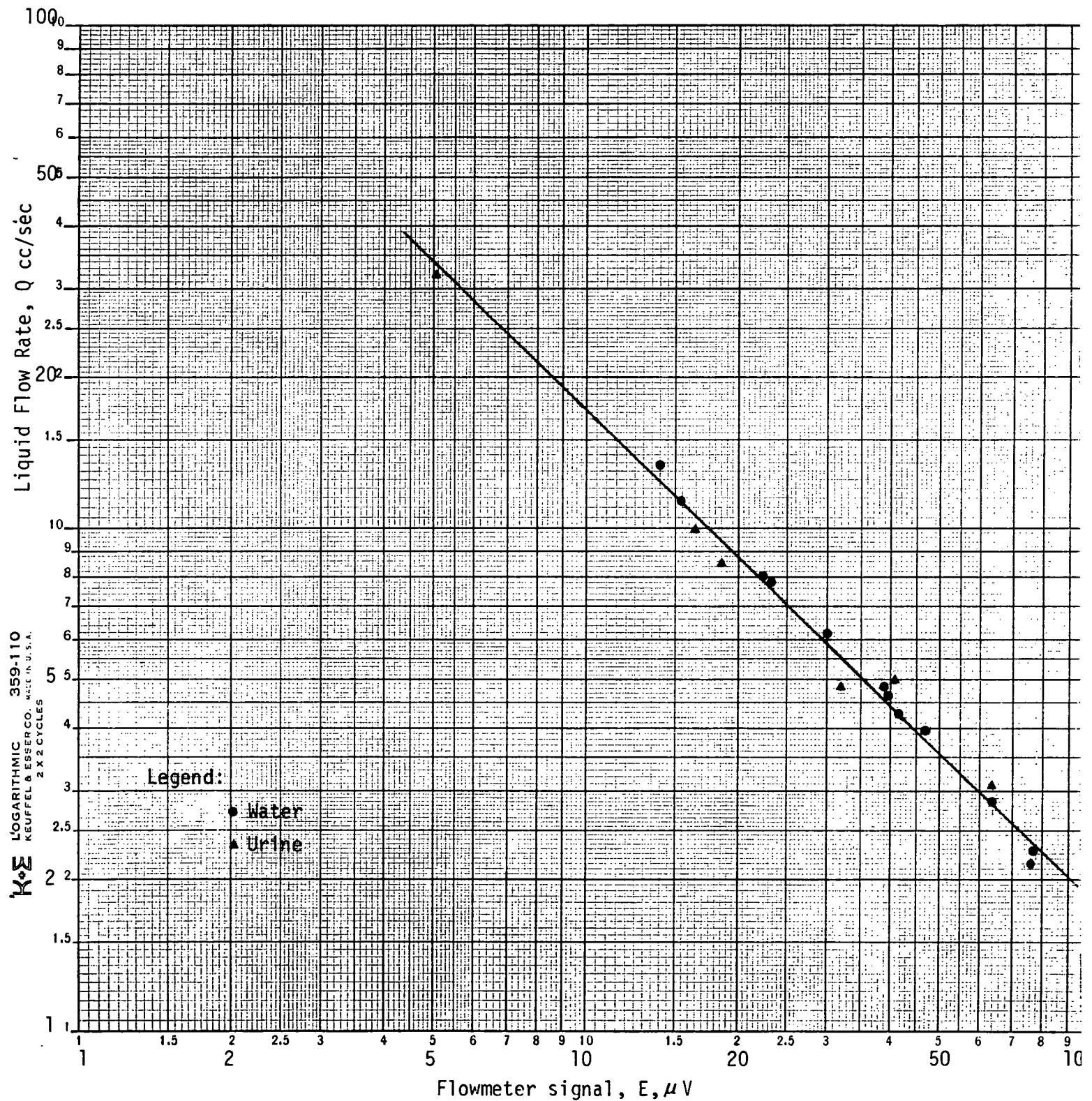


Figure 2. Flow Calibration Curve for Water and Urine for Heater Voltage of 2.9 Volts.

2. Significance of Electrical Resistance of Urine

An analysis was made of the tube wall electrical resistance as compared to the electrical resistance of urine completely filling the inside tube of the thermal flowmeter (worst case). Since the calculated resistance of the urine is more than four orders of magnitude higher than that of the tube wall, all the electric heat can be considered dissipated in the tube wall and nothing in the urine. It will, therefore, not be necessary to electrically insulate the urine from the tube wall.

3. Length to Inside Diameter (L/D) Ratio of the Tube

Because the flowmeter for this application is always in turbulent flow (because of the relatively high velocity air flow that is always present), the L/D ratio that defines the entrance region is about 10. The flowmeter being used has an L/D of about 100 (the thermopile being in the exit end of the tube). Thus, the thermopile is always in the established flow region.

4. Single Phase Versus Two-Phase Flow Conditions

Flowmeter measurements under single phase liquid flow in the turbulent flow regime were found to be in good agreement with two-phase flow data under the limiting air flow conditions outlined in Section II.

5. Depositions or Percipitates

Wall deposits from percipitates will not influence the flowmeter readings because any thermal resistance changes would only influence the radial

heat transfer but not the axial heat transfer (which is what the flowmeter senses).

6. Cross Contamination Control

In Section II, it was demonstrated that the extreme variations in urine density and heat capacity that are encountered are small enough so that the flowmeter signal is not significantly influenced. Thus, cross contamination does not present a problem.

7. Defining the Beginning and End Point of the Flow Measurement

A matter that needed a more detailed description was what happens to the flowmeter signal when liquid flow through the meter has not yet started or when it has ceased. As the liquid flow becomes very small, the output signal becomes very large (Equation 5). However, if all flow were stopped and the air flow component were small, all heat generated by the electrical heater would be lost from the tube by conduction from its ends. If the flowmeter is symmetrical in design, the temperature profile in the tube would be symmetrical and the thermopile signal would be zero (for these specific conditions). In order that the tube temperature does not become excessive under zero flow conditions, a temperature sensor located on the tube wall shuts off the heater at that condition. As soon as the wall temperature drops to the limiting value, the heater is again activated by the temperature controller. This feature can be seen in Figure 3 where a typical flow trace is shown. These "shut-off spikes" at zero flow (before or after a liquid flow

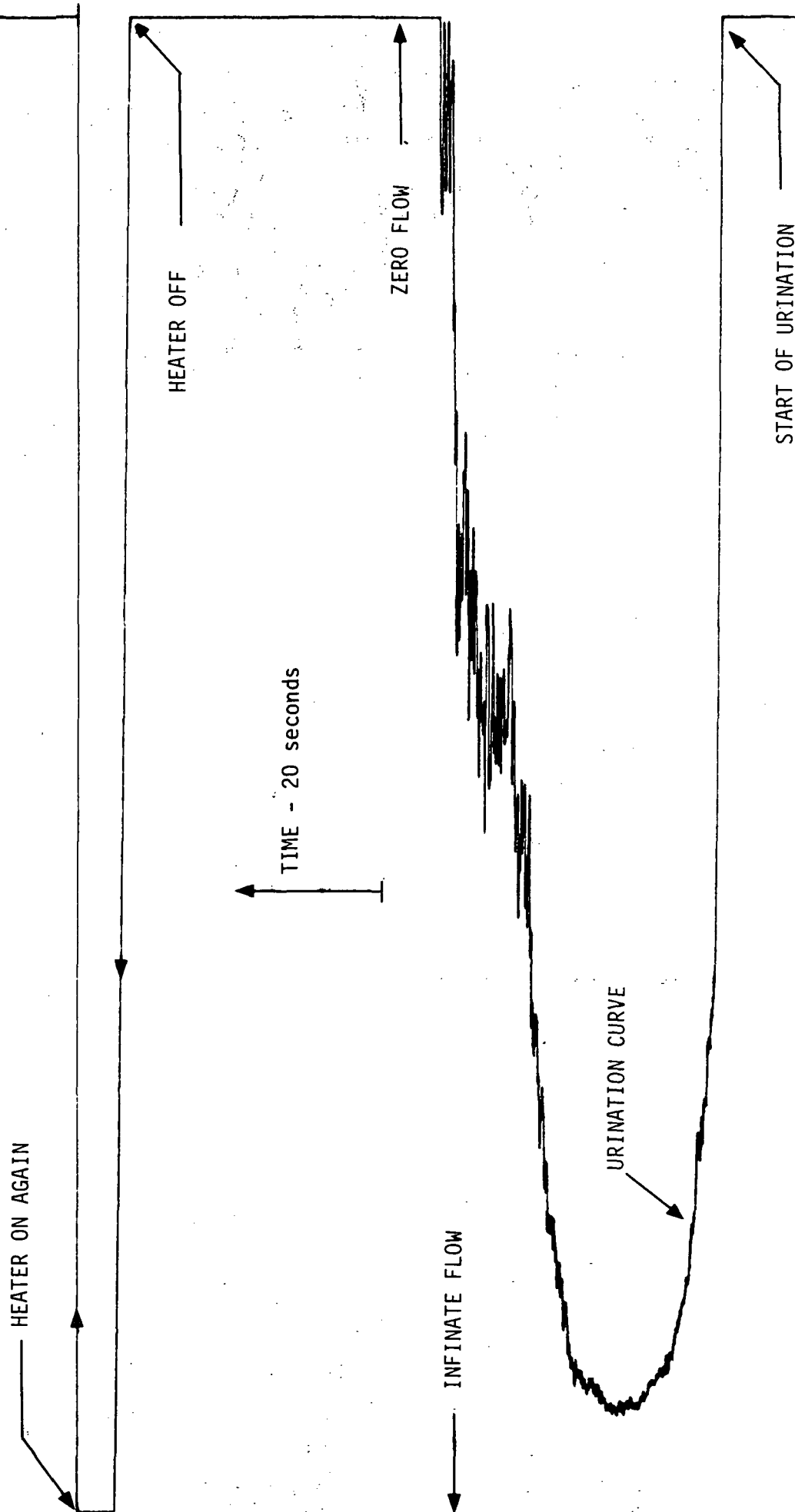


Figure 3. Example of transient output signal during a void including "shut-off spikes" at zero flow.

measurement) may or may not be present depending upon how low the limiting tube wall temperature setting is for the temperature regulator. In the case of Figure 4, for example, such spikes do not exist. Although the starting and stopping features are easily identified on these traces, possible interference with automatic flow integration required the addition of a flow switch discussed in Section V.

8. Differences in Air Flow Rates

The theoretical description of air flow rate on a liquid or urine flow rate measurement in the flowmeter has been described in Section II. For equal volumetric flow rates of air and liquid, it was shown that the presence of the air would cause a change in signal that is less than 0.03 percent. If the air flow rate were ten times as large as the urine flow rate, the error would be less than 0.3 percent.

A number of experiments were performed in the laboratory to verify the predicted air flow effect on the flowmeter output signal. Specifically, liquid flow rates were held constant or nearly so while air flow rates were varied from ten to one hundred fold above the liquid flow rates. Both recording and indicating potentiometers were used to make the study. The air flow effect on the signal was found to agree with predictions; the deviations found were within the accuracy limits of the heater power and recorder zero stability.

← Infinite flow

Zero flow →

Flow off ↑

Flow on ↓

20 seconds

Figure 4. Example of a recorder trace during a void.

The air flow in this flowmeter system plays a very important role; namely, because of its magnitude, it keeps the liquid component in the turbulent state even at low liquid velocities. As has been pointed out previously, under laminar flow conditions, excessive entrance lengths would be required.

9. Differences in Urine Flow Rates

The urine flow rate function was shown in Section II (the inverse function of the axial fluid temperature differential between the thermopile junctions in the flowmeter). The wide range of liquid flow measurements made for the system (15 fold variation), verifies the predicted function (defined by the 45 percent line on log-log paper).

10. Range of Accuracy in Respect to Urine Flow Rate and Urine Volume

Volume measurements were made with urine in order to verify earlier analytical predictions that urine and water would behave in the same way as far as the flowmeter is concerned. Typical urine flow data were shown in Figure 2. The urine flow data are seen to fall close to the water flow data. A microvolt recorder, Honeywell Elektronik 194, with a 100 microvolt full span on a twelve inch chart was used to record the flowmeter signals for various liquid flow experiments. Urine voids were measured by performing an integration of the recorder trace. These results were also compared with actual void measurements and were found to agree within two percent of each other. This value is within the desired accuracy.

11. Gravity Effects

A flowmeter (containing a straight flow tube) was tested in both horizontal and vertical positions in order to verify that gravity effects would not influence flowmeter performance. The tests were made over the complete operating range (from very small flows to the maximum flow capacity of the flowmeter). At constant flow rates, the flowmeter readings were found to be identical for vertical and horizontal orientations of the flow tube. A typical example is shown in Figure 5. The thermal flowmeter will, therefore, yield the same readings in a zero gravity environment as in the Earth's gravity field. Consequently, no calibration will be necessary during space flights.

12. Comparison of Suction and Pressurized Flow

Tests were made to demonstrate that a suction pressure applied at the outlet to the flowmeter with liquid and air flow would yield flowmeter readings identical to those obtained when using pressurized inlet flow. The results from this experiment are shown in Figure 6. Note that no difference in flow performance was found between pressurized and suction flow as expected.

13. AC vs DC Flowmeter Heater Power

A test was made to verify the fact that the flowmeter can operate either on AC or DC electrical heating power. When a DC power source was connected to the flowmeter heater circuit, the flowmeter volume integral for constant flow rates was found to be identical to the AC calibration curve (for a constant heater voltage); the results are noted in Figure 7.

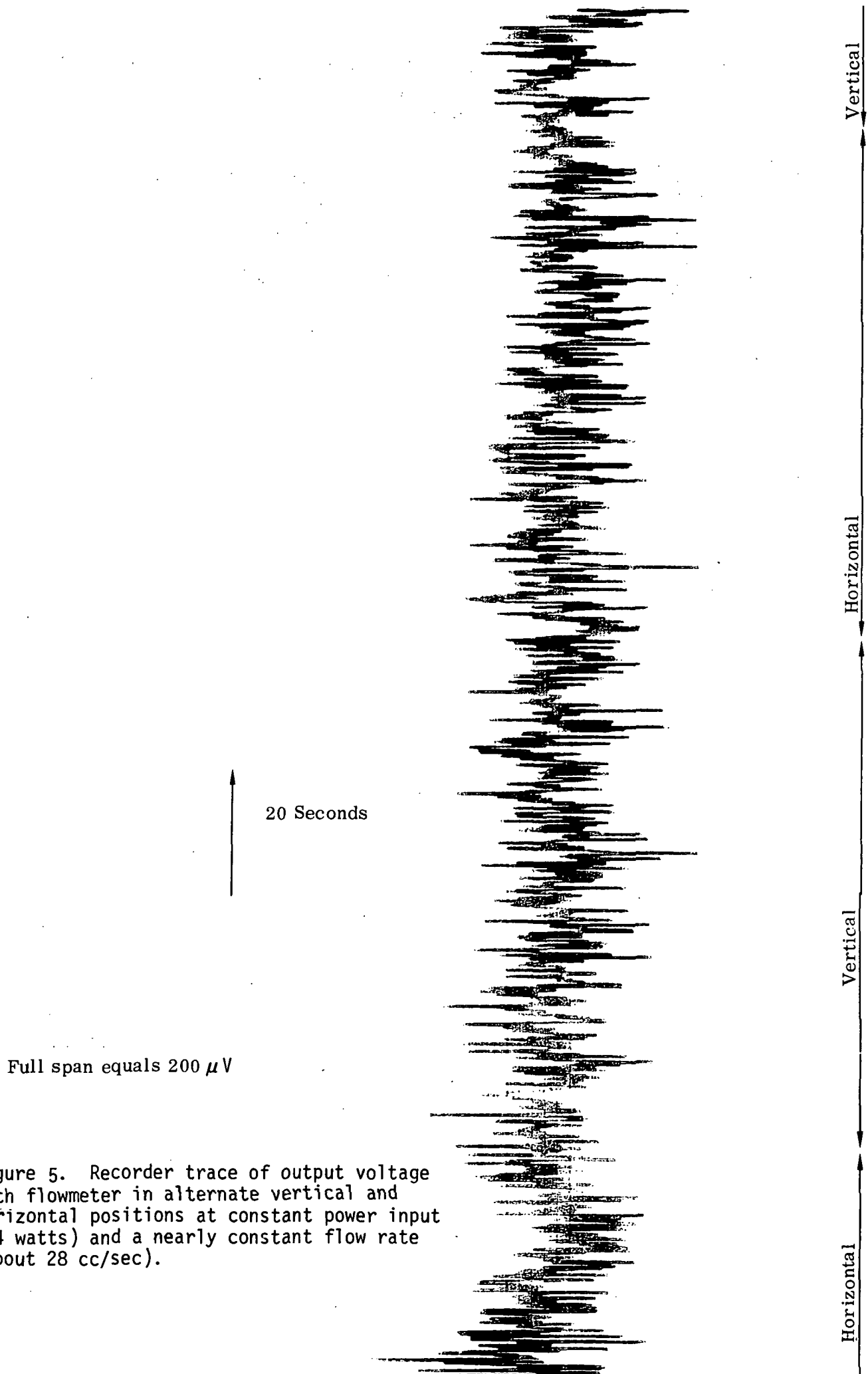


Figure 5. Recorder trace of output voltage with flowmeter in alternate vertical and horizontal positions at constant power input (24 watts) and a nearly constant flow rate (about 28 cc/sec).

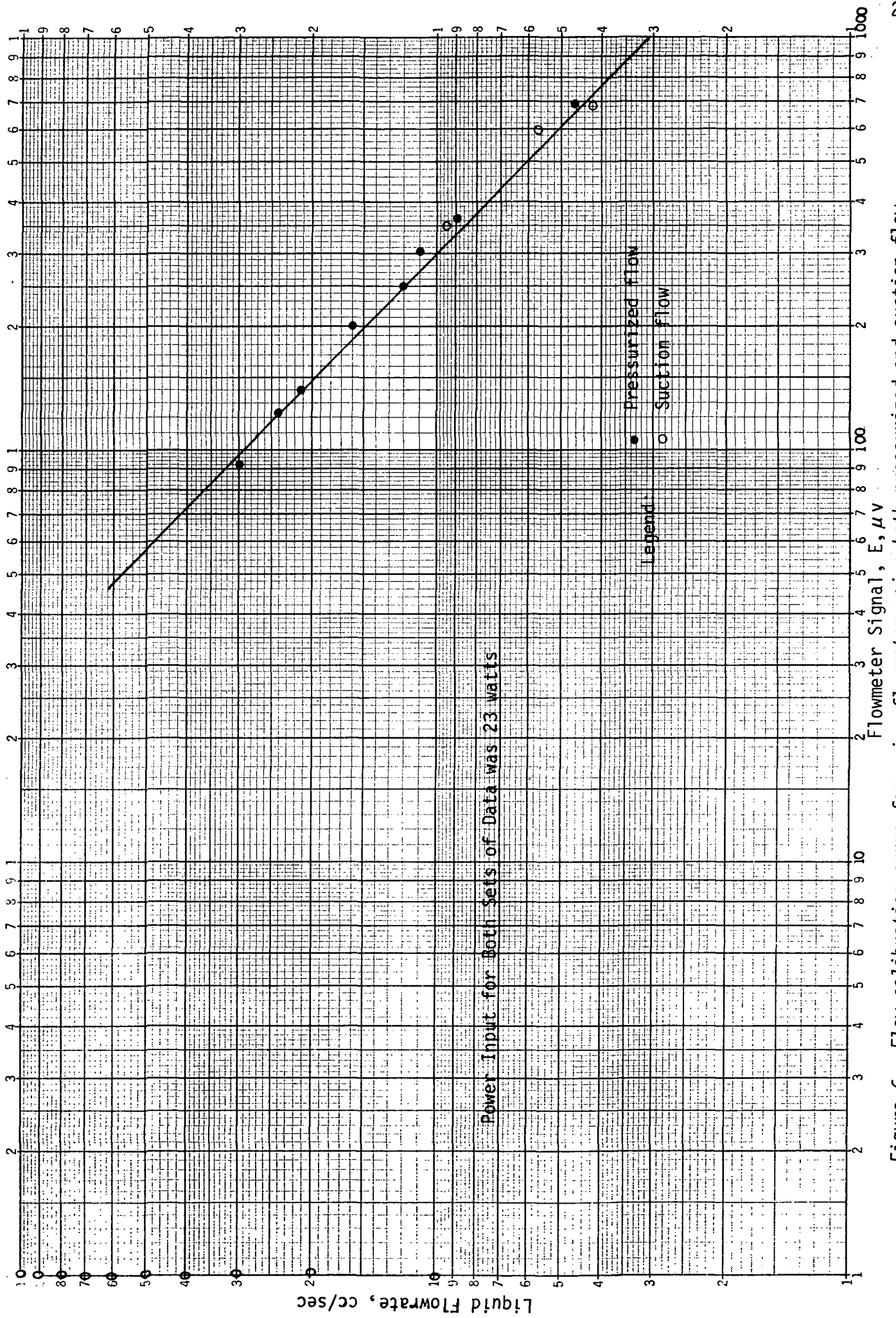


Figure 6. Flow calibration curve for urine flowmeter using both pressurized and suction flow.

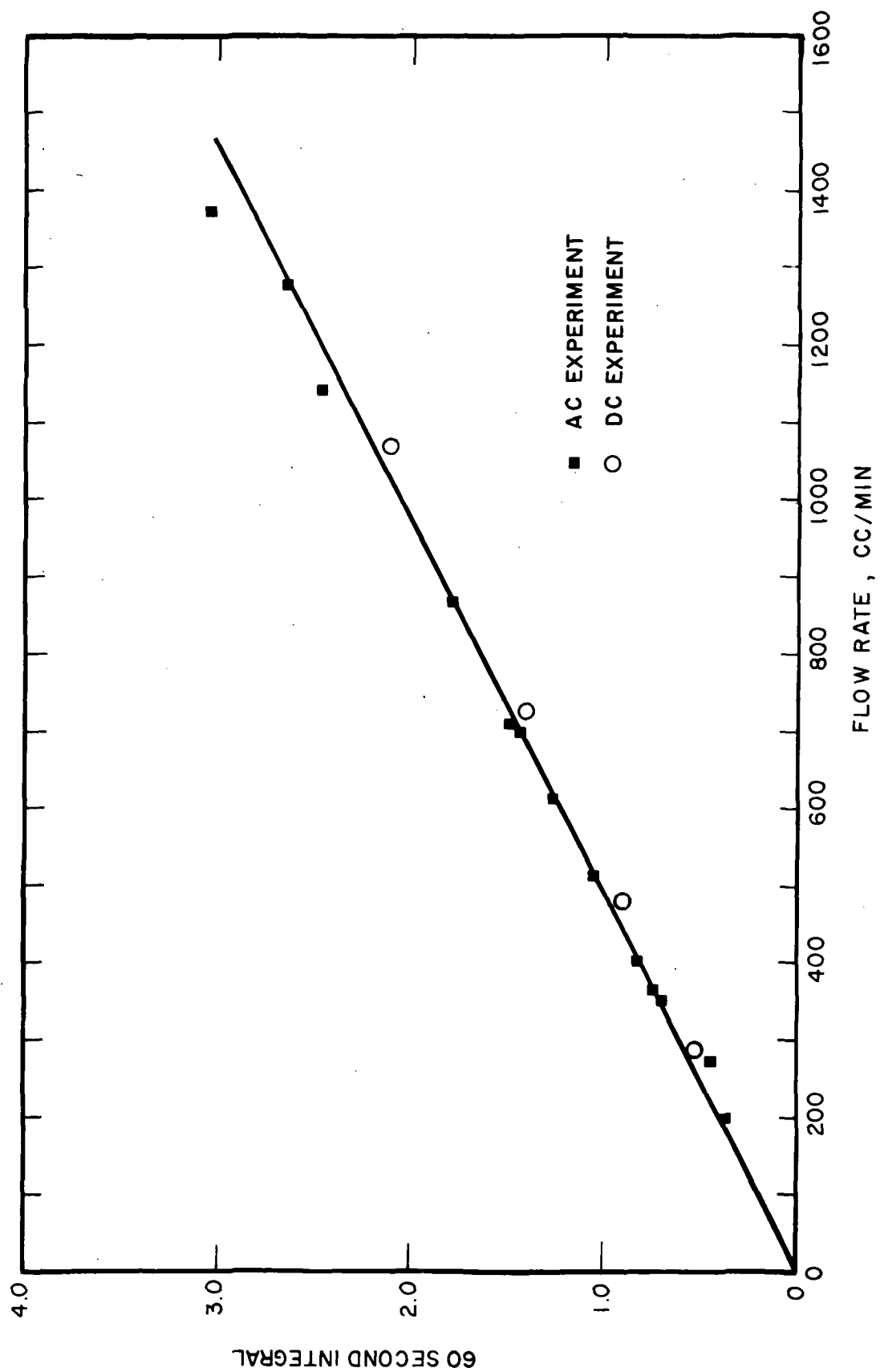


Figure 7. Constant flow rate calibration curve using integrator and prototype B flowmeter.

IV. FABRICATION OF THE PROTOTYPE MEASUREMENT SYSTEM

The potential problem area studies that were performed on this project were outlined in Section III. The results indicated that the predicted performance characteristics discussed in Chapter II for the flowmeter were realistic. If the flowmeter is operated under the conditions specified, urine flow rates and urine volumes can be obtained in a zero gravity environment under two component flow conditions (i.e., requiring no phase separation). It is also pointed out that the system can be adapted to other spacecraft fluid flow rate monitoring requirements.

A view of the complete urine volume measurement system as envisioned for a spacecraft application is shown in Figure 8. The system consists of a flowmeter, an inverter-integrator, a urine volume readout (digital voltmeter), a temperature control switch and a urine receptacle with a flow switch (not shown). A typical installation is shown schematically in Figure 9.

1. Thermal Flowmeter

The prototype thermal flowmeter is contained inside an insulated enclosure. Therefore, essentially all of the electrical resistance heating supplied to the flowmeter tube is transferred to the urine flowing through the system.

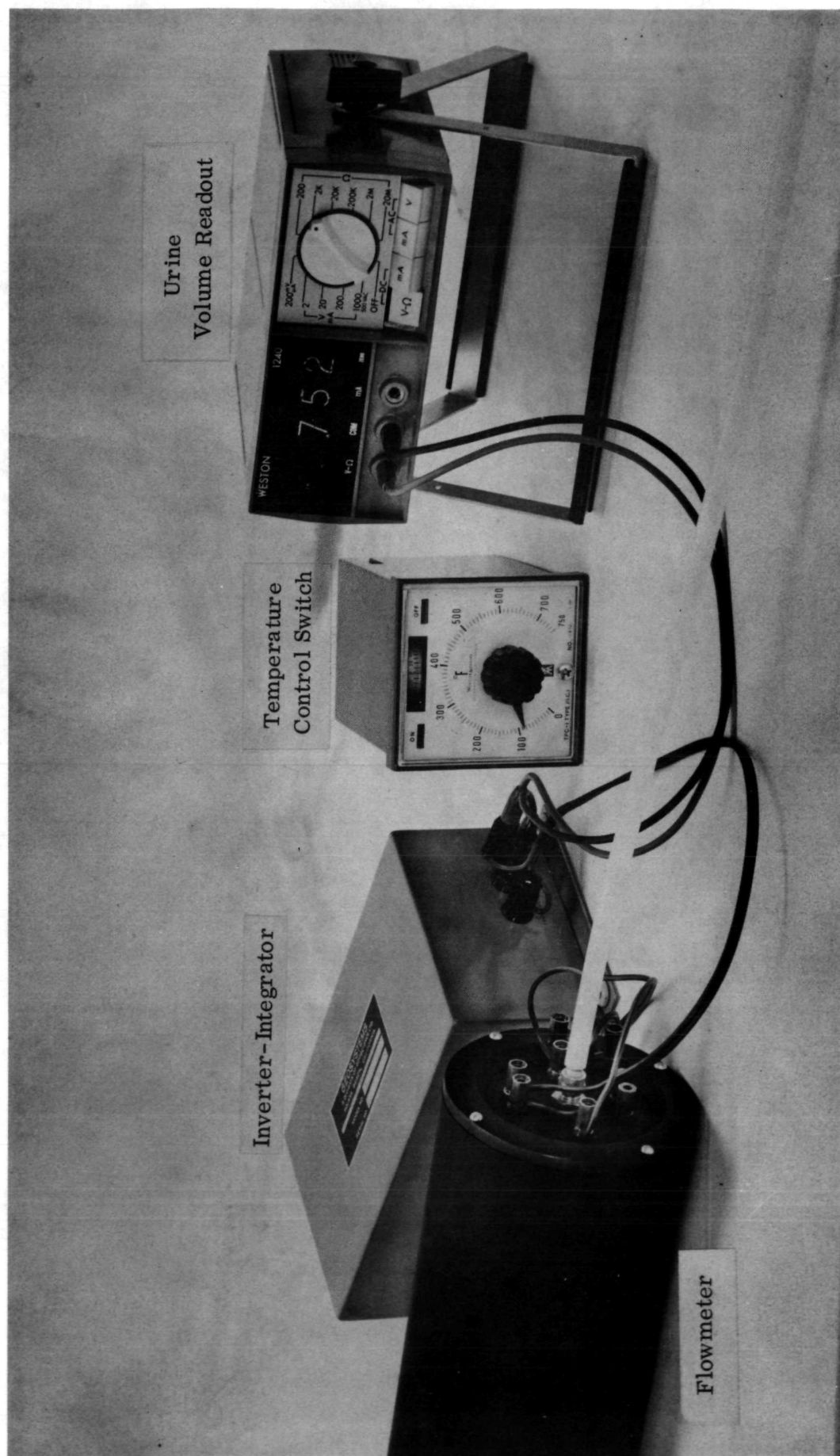


Figure 8. Components for urine volume measurement system.

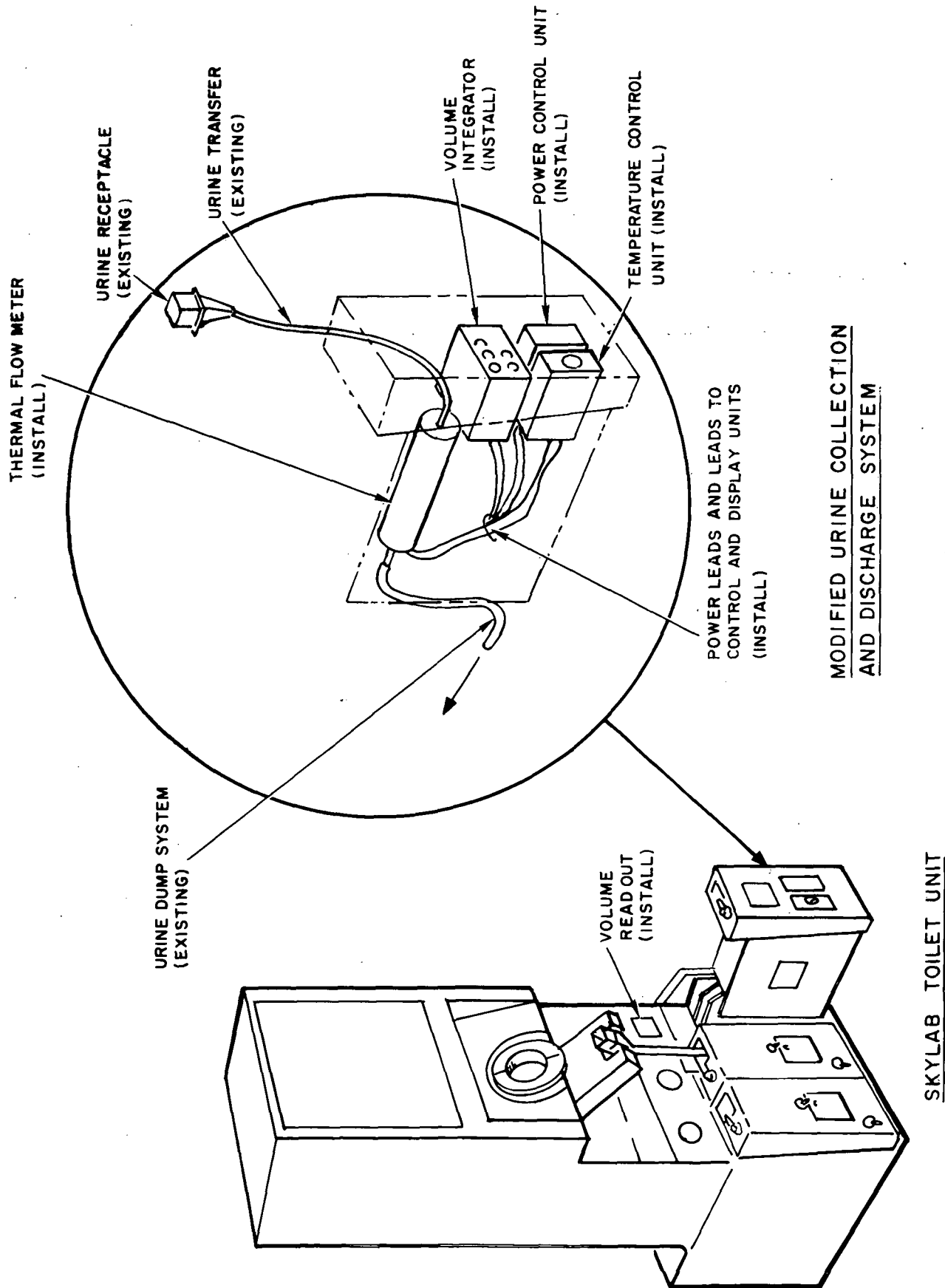


Figure 9. A typical urine volume measurement system installation.

The unamplified electric output signal from the thermal flowmeter varies from 10 microvolts for high urination rates to 500 microvolts for very low urination rates, for a power input of 25 watts. The flowmeter signal can be increased further by increasing the electrical power to the flowmeter.

A number of flowmeter configurations were built to test various design features. One flowmeter consisted of a coiled tube (for compactness) which was contained in a vacuum jacket. This design was found to be difficult to manufacture without further application work.

Four different flowmeters utilizing a straight flow tube were built to test 1) different types of thermopile installations, 2) the effects of variable tube lengths and tube diameters, 3) various flowmeter heaters and 4) thermal insulation.

The best flowmeter had a 0.20 inch diameter flow tube, 16 inches long, operating at 25 watts power input with a maximum urine flow rate of 25 cc/sec (at a 5 psig differential pressure) and an air flow rate of 0.35 cfm (1.00 cfm is the specified allowable flow rate for Skylab).

These limiting parameters can be changed in the following ways:

- a. If the tube diameter is increased or the tube length is decreased, the air flow rate would have to be increased somewhat to maintain turbulent flow in the tube. However, fully turbulent flow cannot be maintained at urine flow rates less than about 2 cc/sec.

- b. If the heating power is increased above 30 watts, the bulk urine temperature rise becomes more than 10°F for a urine flow rate of 1 cc/sec or less. The system is designed to keep maximum urine heating as it flows through the flow-meter to a few degrees Fahrenheit; an average temperature rise for a void is a fraction of a degree Fahrenheit.
- c. The maximum urine flow rate that the meter can receive can be increased by using a larger diameter tube with greater length.

An alternate method for increasing the maximum urine flow rate that can be monitored is to have two flow tubes in parallel inside the same housing as presently used for the single tube. All other parameters would remain unchanged, but the integrator would have to be modified to accomodate the output from two flow tubes.

2. Signal Inverter and Integrator

In order to convert thermal flowmeter output signals to the desired urine flow integral (urine volume), an analog signal processing circuit has been designed and constructed. The functions involved are signal amplification, inversion and integration (see Figure 10).

The unit which has been constructed utilizes solid state discrete-type analog components, the performance of which is independent of ambient temperature variations. This is accomplished by enclosing the entire circuit in a controlled temperature oven.

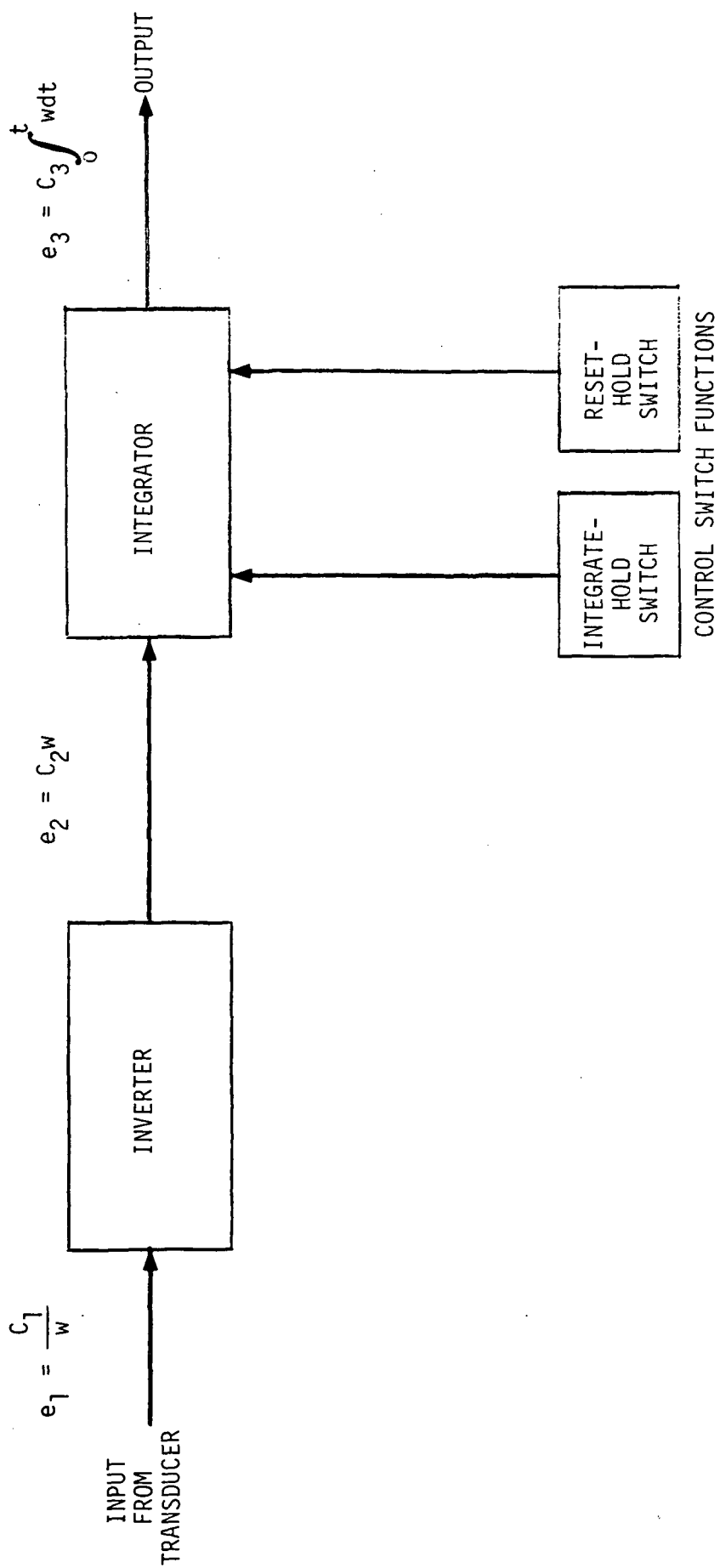


Figure 10. Functional diagram of signal processing unit.

The amplifier section, which has an overall voltage gain of ten thousand in two stages, has a differential input, and is designed to provide an input of ten volts to the inverter (with an input of one millivolt). The bandwidth has been limited to about ten kilocycles in order to decrease the white noise generated by the input transistors. It may be useful to decrease the bandwidth further since the maximum frequency of the transducer signal is at least an order of magnitude below this. The zero point drift of this amplifier is less than 0.1 microvolts, referred to the input. The noise is in the order of one microvolt rms, referred to the input.

The inverter is a transconductance type four quadrant multiplier-divider, which performs the operation of dividing a constant voltage by the amplified transducer signal to perform the inversion process. This component has an input-output relationship which is accurate to one percent over an input voltage range from 0.4 volts to 10 volts, which represents a factor of 25 in flow rate.

The integrator unit consists of five functional blocks in a single package. In addition to the integrator itself, there are: a solid state switch on the input to perform the integrate-hold function; a bound circuit on the input to limit the input signal voltage to 0.7 volts, necessary in order to protect the integrating amplifier; a solid state switch to perform the reset function; and an outlet bound to limit the outlet voltage to the maximum capability of the integrating amplifier,

which is 10 volts. This processing unit is completely solid state, and with the environmental oven requires no day-to-day adjustment. All that is necessary to perform a flow totalization with this instrument is to reset the integrator with one switch and start urination. The power to the flowmeter and integrator are activated automatically by the flow sensor and the control unit. Since the output is at the level of a few volts, it can be read with any convenient panel instrument.

A calibration curve for the integrator based on a controlled input voltage is shown in Figure 11. All units in the combined system were found to operate satisfactorily and the computed volumes agreed with the measured void volumes (within two percent under normal operating conditions).

3. Flow Switch

A flow switch arrangement was developed which turns on the flowmeter heater and integrator simultaneously as urine enters the system. This flow switch (which is activated by a thermal sensor) also turns off the power to the flowmeter heater and stops the integrator when urination ceases. This feature was added for the purpose of automatic operation.

A number of different designs were tested in the laboratory. One flow switch sensor consisted of a thermocouple attached to a stainless steel funnel with perforations (see Figure 12). This unit was positioned at

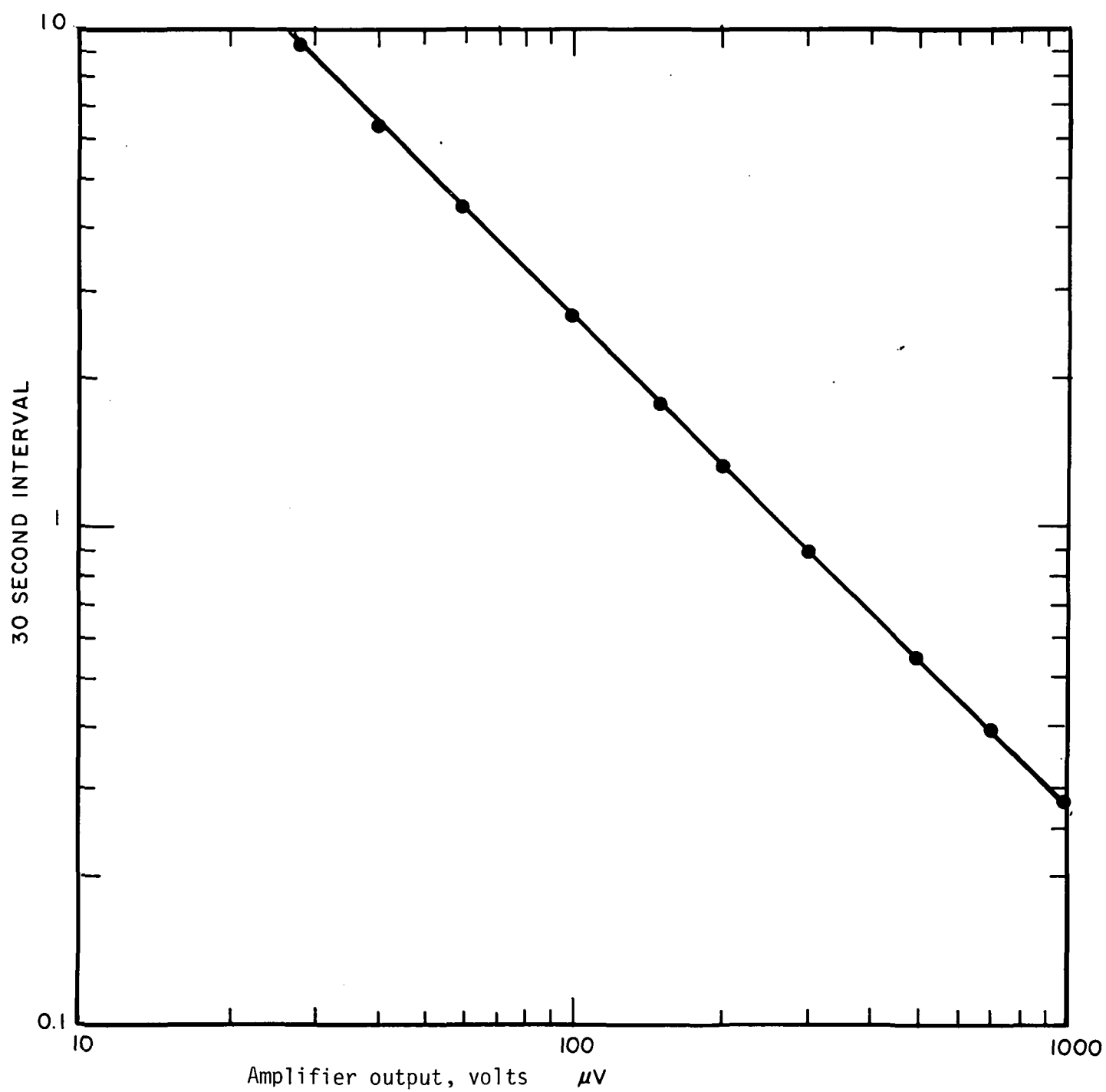


Figure 11. Calibration curve for the integrator.

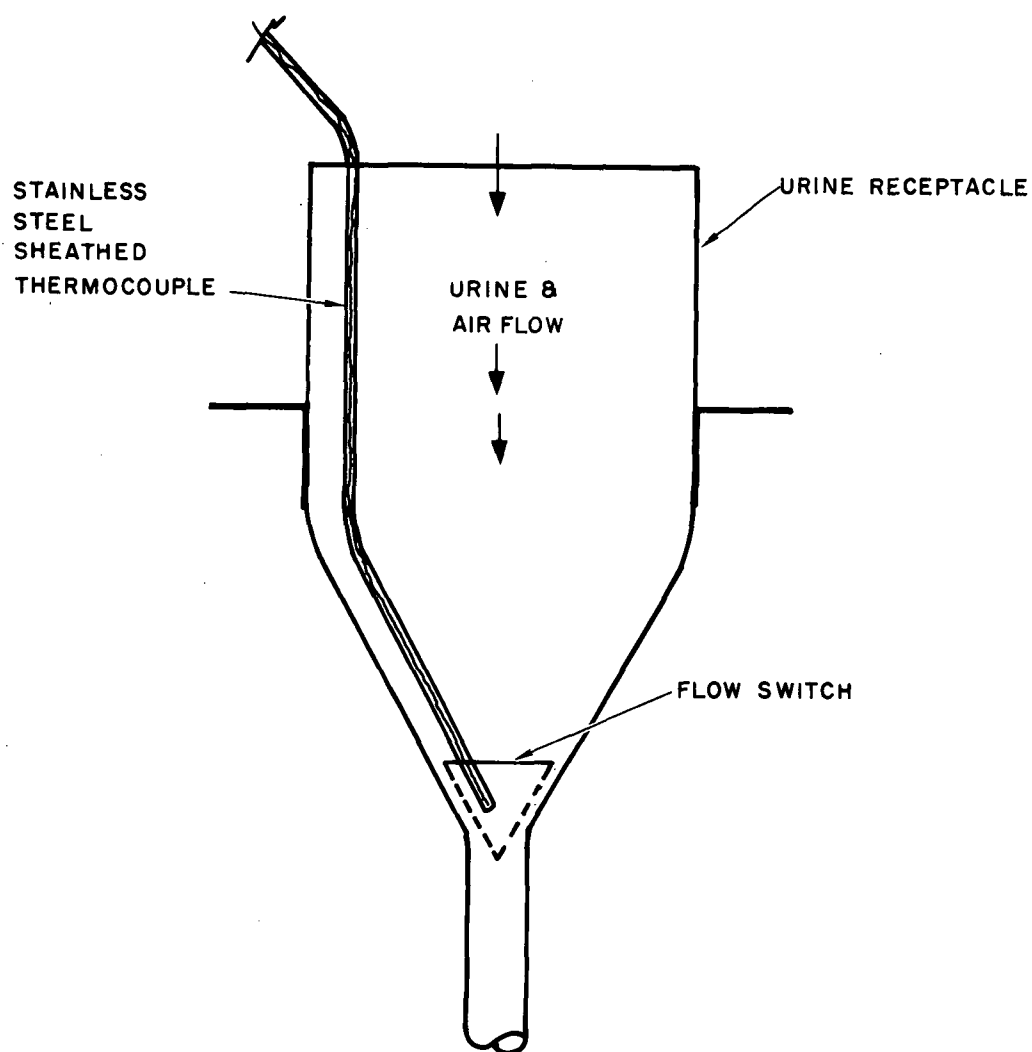


Figure 12. Sectional view of the funnel urine flow switch.

the bottom of the urine receptacle. The perforations allow urine to pass through the funnel, but at the same time guarantee that small drops of urine will contact the funnel and thus increase its temperature sufficiently to activate a temperature controller switch (by the thermocouple sensor). This type of flow switch sensor was found to operate satisfactorily at low to medium flow rates. However, even large perforations were insufficient to allow large volume flow rates to pass through the funnel. Also, the thermal time constant of the sensor was not small enough.

The flow switch must be activated as soon as the first drop of urine contacts the funnel. Thus, the flowmeter heater power is on before the urine enters the downstream flowmeter. When urination ceases, the urine flow switch sensor is cooled by the airflow as soon as the last drop leaves the funnel. However, there must be some time lag in shutting off the flowmeter until the temperature drops to some pre-set value of the temperature controller (sufficient to allow passage of the last drop of urine through the flowmeter).

The spiral flow switch sensor shown in Figure 13 is considered to be an optimized design, having satisfactory time responses. By setting the temperature control switch to on-off operation at 90°F (5°F above the highest cabin temperature of 85°F) the urine flow switch sensor will activate power to the flowmeter and the integrator automatically when urination starts, regardless of cabin temperature. At the highest

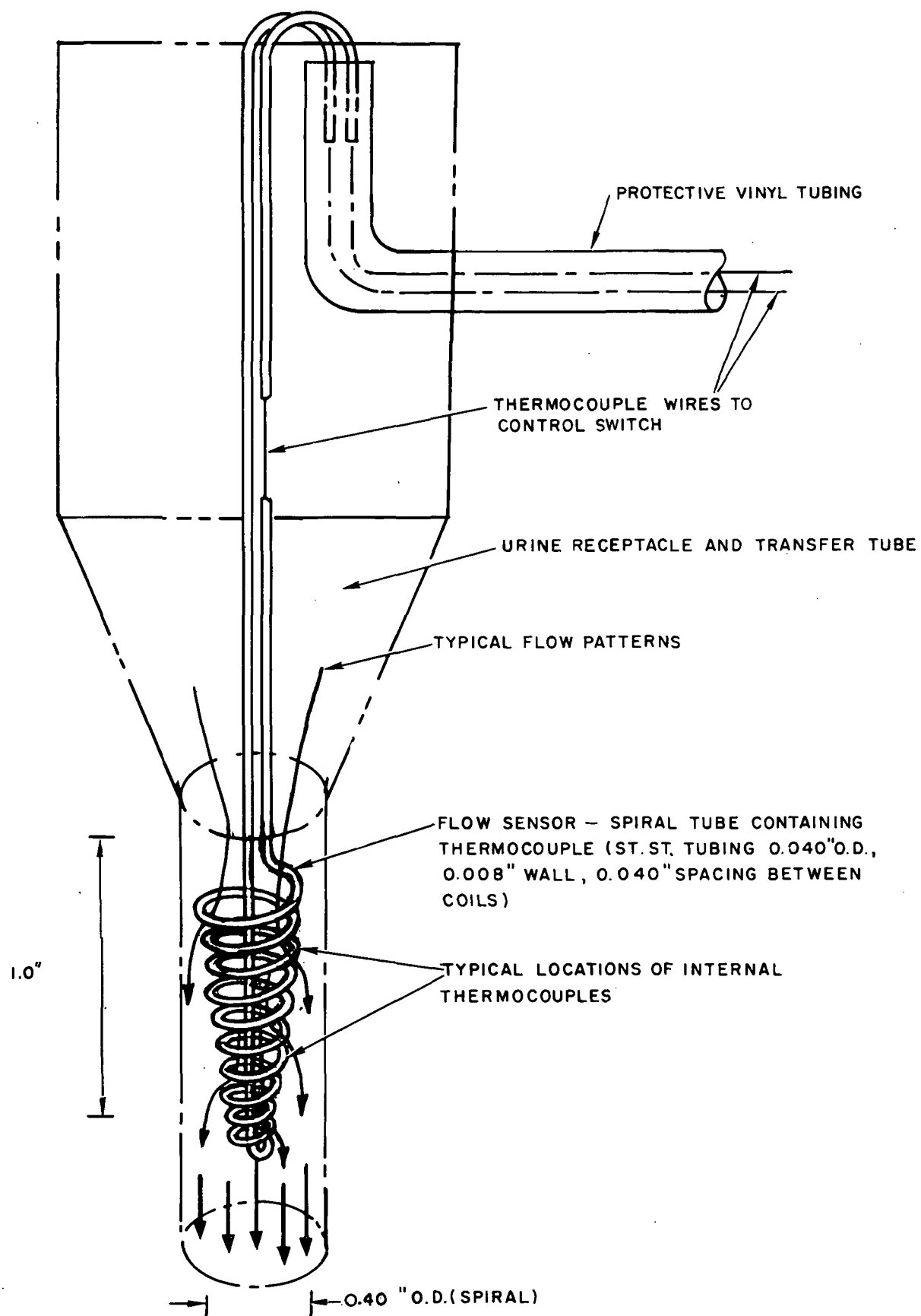


Figure 13. Spiral urine flow switch.

cabin temperature of 85°F, the first drop of urine contacting the sensor will increase its temperature above the 90°F setting in a fraction of a second. At the lowest cabin temperature of 65°F, only a few drops of urine need to contact the urine sensor to activate the power in a fraction of a second; thus, system power is always on before the first urine drop enters the flowmeter.

The airflow, passing through the flow switch after the last urine drop, cools the sensor from urine temperature to the 90°F setting in a time period of 10 to 20 seconds (for room temperatures between 65°F and 85°F). This time lag is sufficient to guarantee passage of the last drop of urine through the flowmeter and without excessive loss of cabin air.

A single spiral flow switch was used in the laboratory to automatically turn on and off the urine volume measurement system (within the above time limits) during the long term performance tests described in Geoscience's memo, GLM-99.

V. LABORATORY TESTING OF PROTOTYPE MEASUREMENT SYSTEM

The investigation of some of the potential problem areas (summarized in Section III) required laboratory evaluations in a test stand, illustrated in Figure 14. A water (or urine) reservoir and a compressed air line were the fluid sources used. Liquid flow was measured with a graduate and a stop watch. Air flow was measured with a Rotameter. The output signals of the flowmeter were measured with recording and indicating potentiometers. AC and DC power sources were used to activate the flowmeter heater and the wall temperature was monitored by a temperature controller. The power into the heater was metered by an ammeter and a voltmeter.

The urine volume measurement system (UVMS) shown in Figure 14 was used to calibrate the thermal flowmeter and measure its time constants. Calibration results have been discussed previously. Response times (time constants) for sudden flow changes were measured to be 1 to 1-1/2 seconds. It is felt that for urination periods of 20 to 60 seconds, such time transients will not effect the overall volume measurements significantly; also, the starting and ending transients are compensating types.

Additional system tests and verifications are briefly outlined in the following paragraphs.

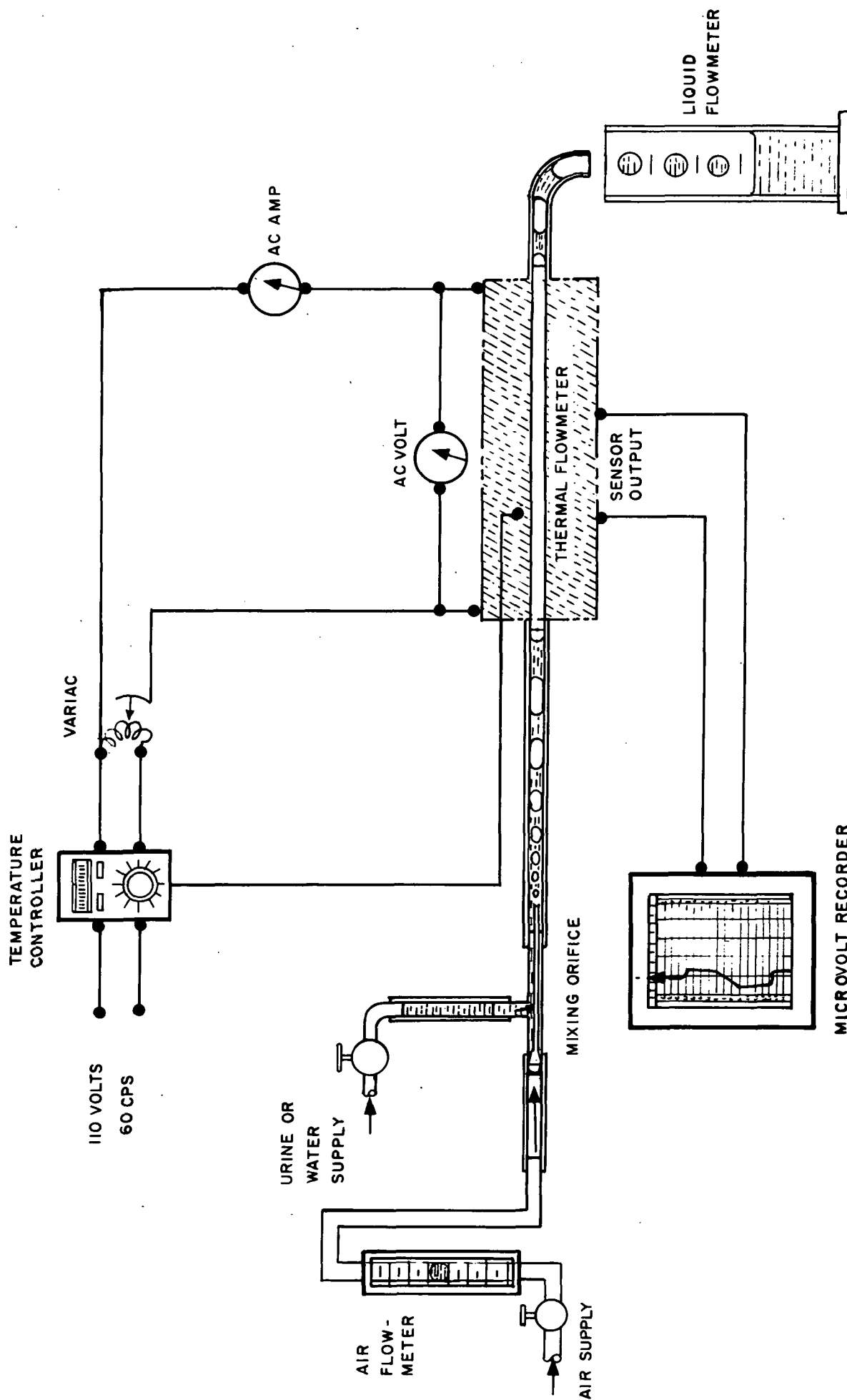


Figure 14. A schematic diagram of the laboratory flow test stand.

1. Environmental Temperature Control

If there is a large difference in temperature between the urine and the cabin environment, transient heat transfer can occur if the thermal insulation is insufficient. Therefore, in order to make this temperature difference small, super insulation or environmental temperature control must be used; the latter method was employed.

An external electrical heater was installed on the outside of the flowmeter. The external heater was then activated with a 28-volt AC or DC circuit so that the flowmeter was maintained at normal urine temperature. The system is therefore ready for urination measurements at any time.

Experiments were performed with the flowmeter maintained at 100°F and liquid flow temperatures of 95°F, 100°F, and 105°F. In all cases, the zero deviation on the recorder (with no flowmeter heater power on) was less than the two percent accuracy in flow rate being sought. The external heater was therefore proven to control the flowmeter temperature satisfactorily.

2. Suction Air Flow Arrangement

A suction air flow arrangement was assembled for the final flowmeter test work. In this system, air and urine flows into a urine receptacle, through the flowmeter and into a receiving tank. A vacuum pump then removes the air from the tank.

When the flowmeter system was operated in this configuration, the measured flow rates were identical to the ones reported earlier for pressure flow. The measured urine voids were accurate within two percent of the actual voids.

3. Long-Term Functionability Tests

The flowmeter was used daily during urine voiding by two staff members of Geoscience for a six-week period (see GLM-99 for details). The UVMS functioned satisfactorily during the six-week test period with no change in calibration. Calibration was checked weekly by adding 150 cc of urine into the UVMS and comparing the integrals from the system recordings. In addition, these tests demonstrated long-term reliability of the electrical components. The flowmeter tube was inspected at the end of the six-week test period. There was no deposit of any kind inside the tube, which had its original shiny surface. Apparently, the high velocity, turbulently flowing urine-air mixture does not allow the deposition process to occur.

The flowmeter was operated as it would be in a spacecraft installation. The external heater was on continuously; thus maintaining the flowmeter between 98°F and 100°F at all times, so that it was ready for urination. Before urination was initiated, the air suction pump for the system was turned on. Urination into a receptacle containing a thermocouple temperature sensor activated the power to the flowmeter and recorder as

soon as the first drop of urine entered the receptacle. One drop of urine was sufficient to increase the temperature of the flow switch sensor. When urine flow ceased, the sensor of the switch cooled and then deactivated the flowmeter and recorder. Thus, the urine volume measurement system was operated automatically during each urination as it would in a spacecraft. Long-term functionality of the overall system in automatic spacecraft operation was thereby demonstrated.

4. Void Measurement Using the Inverter-Integrator

Typical volume measurements were made in the laboratory using the inverter-integrator and a prototype flowmeter. The integrated volume output signal was shown earlier in Figure 11 as a function of constant volume flow rate in 30 second runs. Note that the experimental points deviate from the straight line by less than 1.5 percent. In a second set of experiments, the volume flow rate was varied to simulate typical urination flow voids. The void volume was again plotted as a function of the integrated output signal in Figure 15, and the experimental points deviated from a straight line relationship by less than 2 percent.

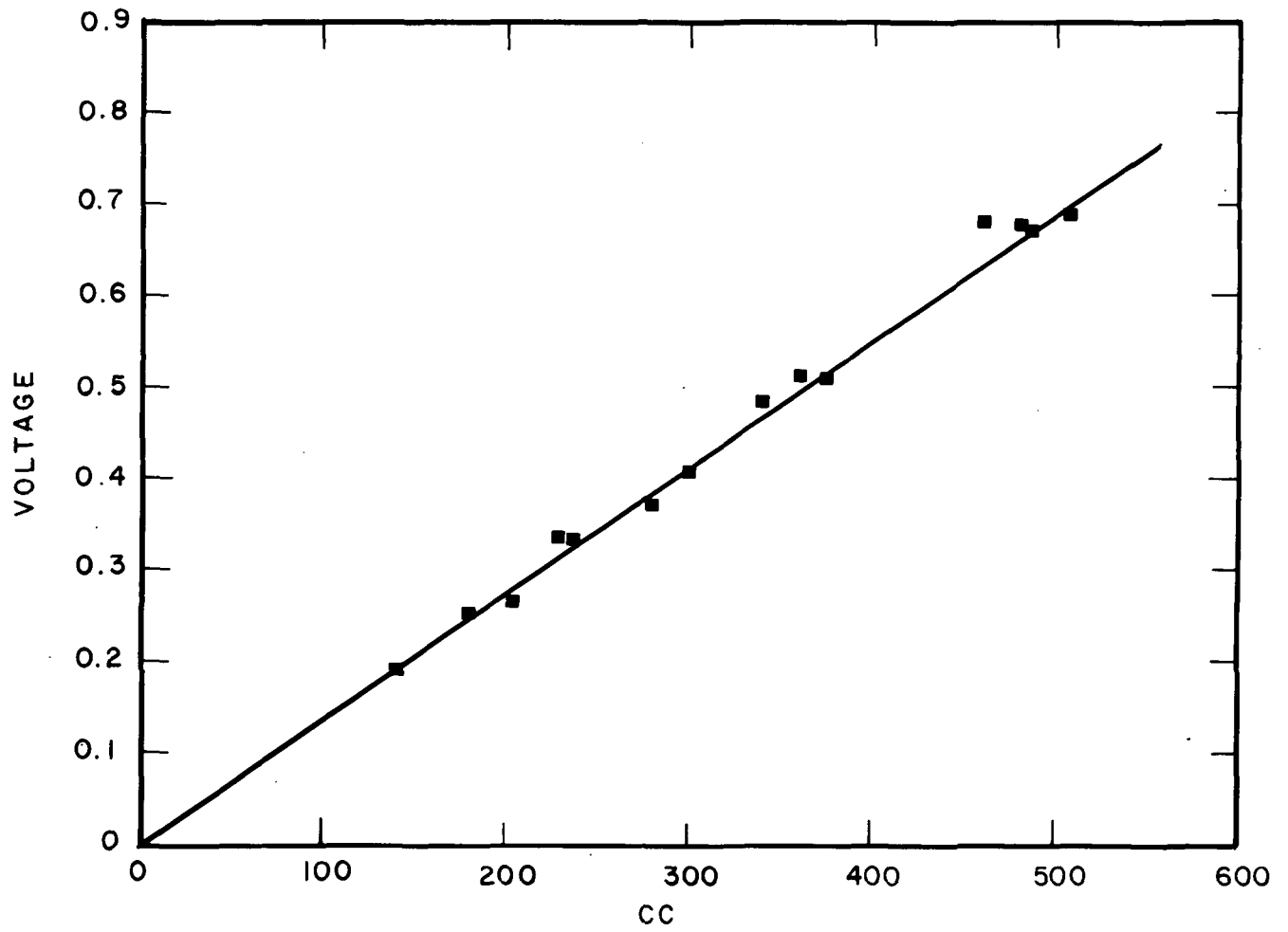


Figure 15. Typical urination voids, integrated vs. measured.

VI. CONCLUSIONS

A compact flowmeter was fabricated, "Prototype E," using a flow tube 16 inches long and 0.19 inches I.D. The urine flow range with this flowmeter is 1 cc/sec to 24 cc/sec using an air flow of 0.35 cfm and a maximum pressure drop of 5 psig across the flow tube (see Figure 16). For an air flow rate of 0.25 cfm, this flowmeter will handle urine flow rates from 3 cc/sec to 40 cc/sec. Thus, it is noted that this system closely satisfies the typical requirements cited for space vehicle use.

Further refinements of the urine volume flowmeter are possible, but were not within the scope of the present contract. The prototype flowmeter can be modified to broaden its operating range as desired. Also, a flowmeter consisting of two parallel flow tubes similar to "Prototype E" flowmeter (16 inches long and 0.19 inches I.D.) would satisfy excess urine void requirements.

A compact inverter/integrator unit was used in the program calibration tests and was found to give void measurements within the specified two percent accuracy. Also, a new urine flow switch is included which successfully activates and deactivates system powers automatically during urination.

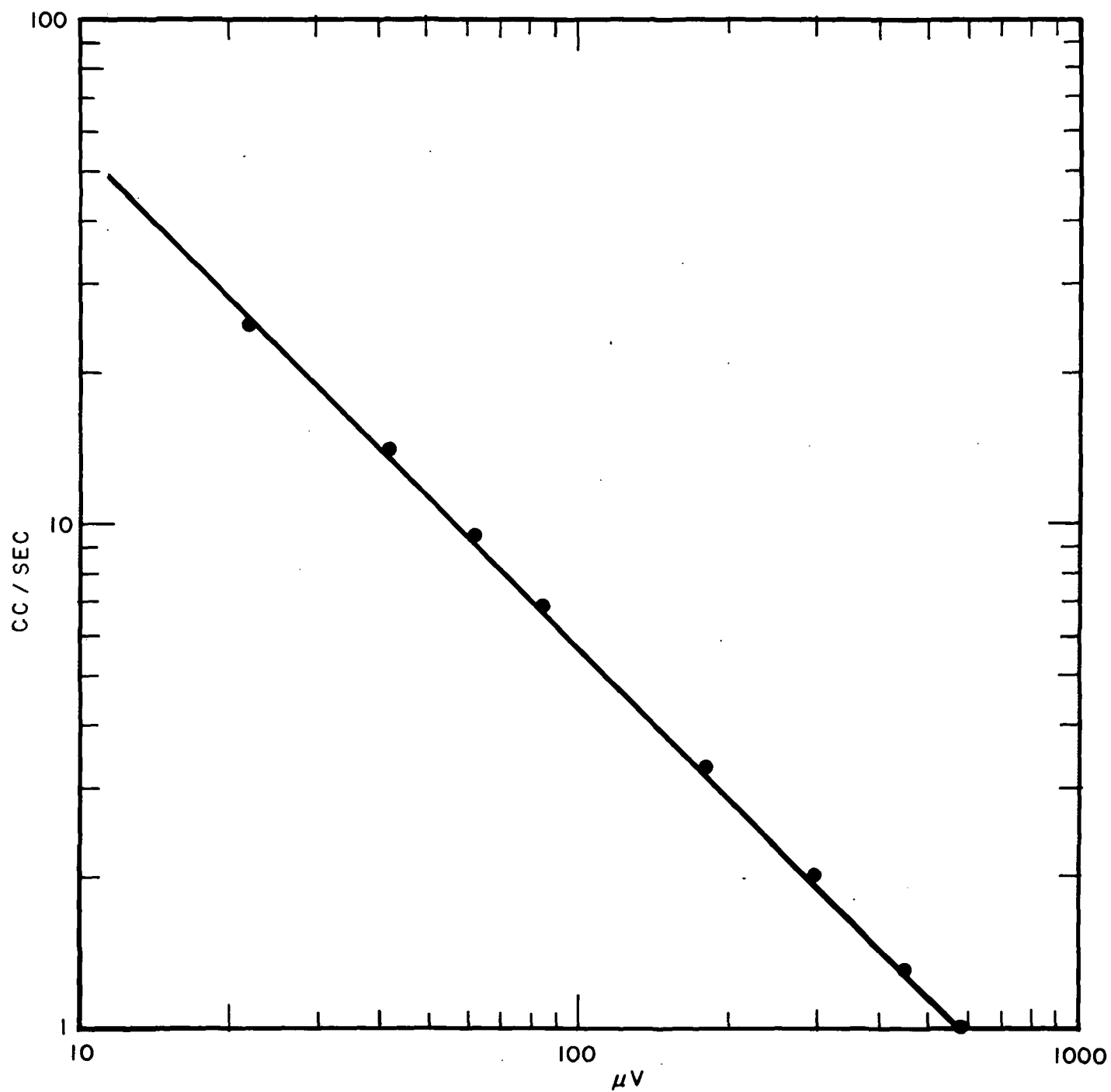


Figure 16. Calibration curve for "Prototype E" flowmeter using 25 watt power.

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